# Lessons Learned from the February 27, 2010 Maule, Chile Earthquake

By Mark Yashinsky, Caltrans Office of Earthquake Engineering

Caltrans Office of Earthquake Engineering investigates bridges after large earthquakes to see if changes are required to our seismic design criteria. Therefore, I was glad to be chosen to be part of the combined **Pacific Earthquake Engineering Research Center / Earthquake Engineering Research Institute** team that went to Chile on March 13th to study the effects of the M8.8 February 27, 2010 Maule, Chile Earthquake.

South America has a 4000 km long fault running along the Pacific Coast (where the Nazca and South American Plates come together). This boundary is the source of frequent devastating earthquakes including the 1960 M9.5 temblor which was the largest earthquake ever recorded. The Maule earthquake had a bilateral rupture that began just offshore and propagated about 270 km to the north and 270 km to the south and deep under the South American Plate (see Figure 1). More information on this earthquake is at: (http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/).

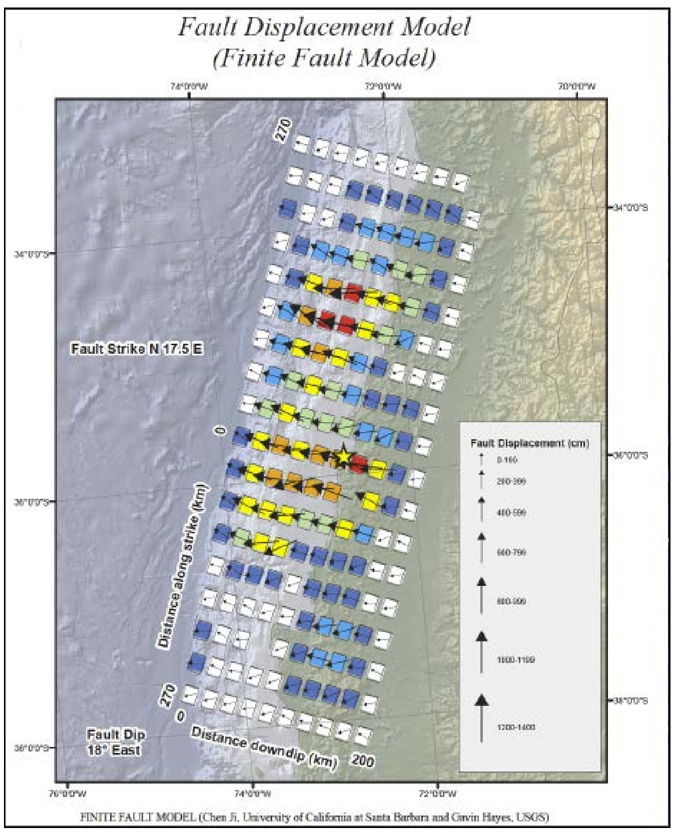


**Figure 1. Fault Rupture.**

The PEER/EERI Bridge Team consisted of Scott Ashford (Oregon State University), Luis Fargier (Universidad de los Andes, Merida), Rodrigo Oviedo (Universidad Catolica de Chile), and myself. We traveled south to Temuco on March 15th, and then slowly made our way back to Santiago (a distance of 700 km in each direction). The following are lessons learned by studying the bridge damage and thinking about our current practice.

**1.Caltrans current seismic criteria would have addressed most of the bridge damage.**
Most of the damage we saw was caused by lack of restraint along the load path and not enough seat length. Caltrans current seismic criteria requires balanced structures with large seats, good continuity of reinforcement, and well-confined ductile members. This would prevent the kind of collapse that occurred on the Quiliera Overhead (Figure 2).

**Figure 2. Collapsed Two-Span Quiliera Overhead in Santiago.**

**2. Government management of highways ensures seismic criteria is followed.**
In the 1990s Chile wanted to grow its infrastructure, even though they were lacking in funds. Their solution was to privatize most of their major highways and expressways. Unfortunately, this resulted in bridges that did not include as many seismic resisting details as those used in older bridges. Almost all of the damage we saw was to bridges built in the late 1990s, after the roads became the property of corporations.

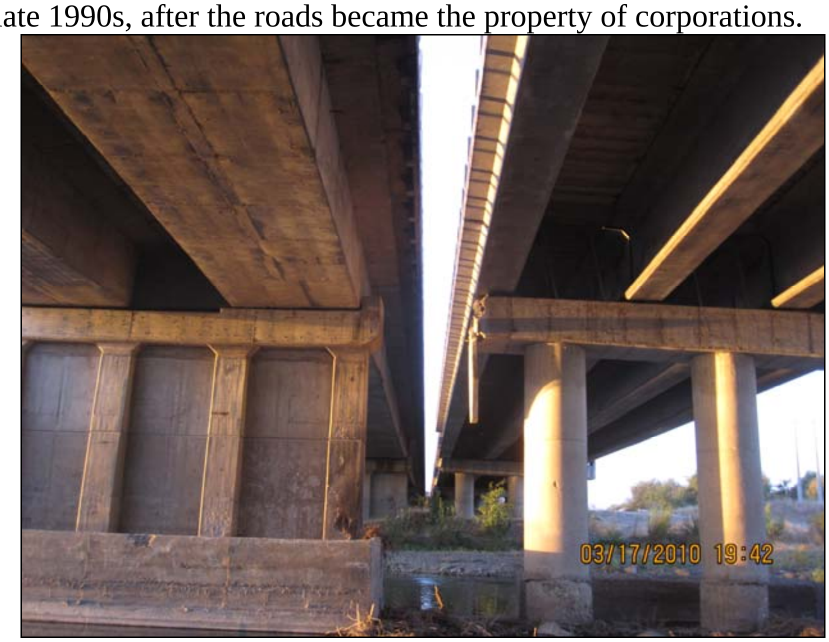


**Figure 3. Puente Perqui Lauquen Carrying Route 5.**

**3.Urban interchanges should have balanced stiffness and structural period.**

**Puente Llacolén** was the newest bridge across the Rio Bio Bio. It was meant to carry traffic from adjacent streets and highways across the river and so it had stiff structures at both ends to accommodate several ramps and connectors. It is likely that the more flexible ramps had large displacements during the earthquake and moved out of phase with the stiff, eastern end of the bridge. As a result several of the ramps became unseated during the earthquake (Figure 4). This stopped all traffic across the river until temporary (Bailey) bridges could be erected over the fallen spans to allow one or two lanes of traffic to flow in each direction. We want adjacent frames of bridges to have about the same stiffness, mass, and period so they can move in-phase and so stiffer elements don't carry too much force. A better solution for these connectors is what we call an 'Urban Interchange' such as Caltrans designed for the Carmenita Interchange in Norwalk, where an effort was made to make all the frames have about the same stiffness.

**Figure 4. Collapsed connectors to the Puente Llacolen (photo courtesy of the Japan Society of Civil Engineering (JSCE)).**

**4. Past good performance cannot ensure good performance in future earthquakes.**

Because the Rio Clara Bridge was built in 1870 and had survived many large earthquakes, we might assume that it was highly resistant to earthquakes despite being a masonry bridge. However, strong ground motion can vary and it wasn't until the most recent earthquake that ground motion occurred that caused the bridge to collapse (Figure 5).

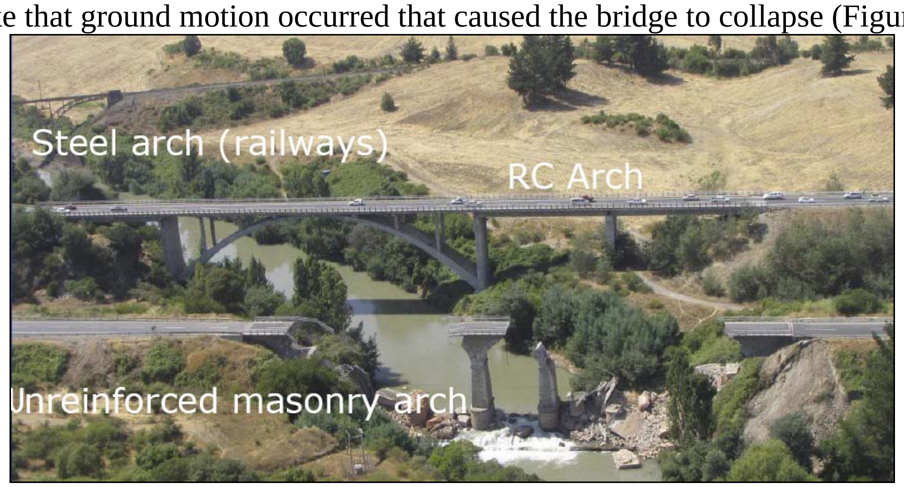


**Figure 5. Collapsed Puente Rio Claro (photo from JSCE Team).**

**5. Two Span Overcrossings appear to be vulnerable to twisting.**
We tried to stop and look at all the damaged two span overcrossings we saw while driving on Route 5. Every one of these damaged structures, even those with little or no skew, had rotated about a vertical axis at the center pier (Figure 6). Since we traditionally perform a linear static analysis of each bent (without twisting), this behavior needs to be carefully studied to see how it impacts Caltrans' seismic procedures.


**Figure 6. Twisting of a Two-Span Overcrossing on Route 5.**

**6. Large magnitude earthquakes don't necessarily produce more damage.**
We drove hundreds of km along Route 5 without seeing bridge damage (Figure 7) from this **M8.8** earthquake. In contrast the 2008 Wenchuan Earthquake was **M7.8** and produced very large areas of complete destruction. The 1995 **M6.8** Kobe Earthquake caused damage on almost every bridge in downtown Kobe. However, bridge damage did occur over a much larger area during the Maule, Chile Earthquake, up to 700 km apart.

**Figure 7. We drove long distances on Route 5 without seeing any bridge damage.**

**7. Having parallel bridges increases the chances of having one bridge to carry traffic.**
Most major expressways have been widened to include an older and a newer bridge standing side by side. In almost every case either the newer bridge with poor seismic details collapsed (Figure 8) or an older bridge that had a short seat or other bad details collapsed. We seldom saw both bridges collapse, which was fortunate since it allowed traffic to squeeze onto the remaining bridge without a major detour.

**Figure 8. New bridge with poor details collapsed while older parallel bridge (to the right) remained standing and was still in use on Vespucio Norte in Santiago.**

**8. It's beneficial to build highways farther away from faults**
The Pan-American Highway is built conveniently far enough away from the major fault to escape the most severe damage from the earthquake (Figure 9). California's I-5 is also some distance from most faults (except in Southern California).

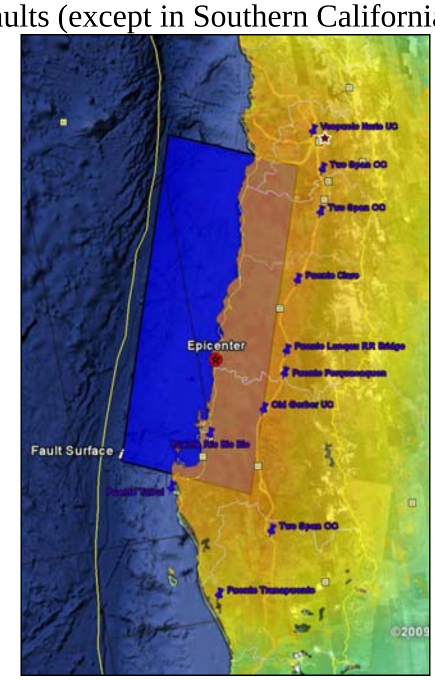


**Figure 9. The Pan-American Highway is located east of the major fault**.

**9. Skewed bridges tend to rotate off their seats.**

For a variety of reasons (geometric boundary conditions, bias in direction of displacement, eccentric location of mass, etc.) we see a lot of unseated skewed bridges after earthquakes (Figure 10). The lesson would be to provide very large seats on skewed bridges and also to perform research into this issue.


**Figure 10. Puente Perquacaquen, a single span skewed bridge on Route 5, became unseated and collapsed during the Maule Earthquake (photos courtesy of JSCE).**

**10. Lateral spreading can cause significant bridge damage.**

Puente Juan Pablo II is an older bridge and it is one of the few examples of bridge column damage that we saw during the earthquake. The eastern end of this long bridge moved towards the river, breaking a short stiff two-column bent at the water's edge due to lateral spreading of the bank. This behavior needs to be better addressed by Caltrans.


**Figure 11. Lateral Spreading Damage at Puente Juan Pablo II (photos from JSCE).**